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Comment on nhess-2022-73

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Referee comment on "Seismic risk scenarios for the residential buildings in the Sabana Centro province in Colombia" by Dirsa Feliciano et al., Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2022-73-RC1, 2022

Overall Description

This article presents seismic risk results from 18 earthquake scenarios in the Sabana Centro province, an intermediate hazard zone in Colombia. The 18 scenario events were chosen based on hazard disaggregation results on a site within the region of interest, for a 475 years return period hazard level. The epicenters of the scenario events were located within the region. The exposure model was gathered from previous studies, complemented with census data and remote surveys. Finally, the set of fragility curves for the considered typologies was gathered from previous studies. Results show that, on average, the occurrence of one of the scenario earthquakes might result in about $800 million USD of economic losses (about $1000 million USD when adjusted by social vulnerability) and about 20% of all the buildings collapsing.

The study is well performed and written. In terms of scientific merit, although the article does not provide new methods for seismic risk assessment, it provides novel results on the seismic risk faced by the Sabana Centro province. I have some comments that may help to improve the quality of the article (I have marked the most important issues that I comment). In particular, compared to the damage produced by previous earthquakes around the World, the numbers presented in this article seem to be too high, especially considering that: (1) these are mean values, not low-probability values (thus they are not even the “worst-case scenario”); and (2) the authors state that the risk results should be considered as a lower bound. Therefore, I strongly suggest a careful revision and discussion of the results.

Specific Comments (Individual scientific questions/issues)

1. Line 130: The authors state that the Bucaramanga’s seismic nest earthquakes occur at depths between 140 and 200km. However, in Figure 3 it is possible to observe several

events at depths between 70 and 150km. I suggest the authors comment something about this inconsistency.

2. Line 144: The description of Figure 3 does not match what is observed in the figure. The authors state that Figure 3 shows: (1) close (distance < 75km) and shallow (depth < 70km) events; and (2) far (150km < distance < 200km) and deep (depth > 70km) events with magnitudes greater than 6.5. However, the figure presents many other events. For example, there are shallow events at distances larger than 75km with magnitudes lower than 6.5, deep events with magnitudes lower than 6.5, etc. The description and the figure should be consistent.

3. Line 155: The authors state that the population centroid is located within Tenjo. Moreover, they use this municipality throughout the article as a reference (e.g., Figures 2 and 3). However, given the map provided in Figure 6c and the population of each municipality provided in Table 1, it seems like the centroid should be located somewhere between Zipaquirá and Chía (probably within Cajica), which are the two municipalities with the largest populations.

4. Figure 4: What is the distance type of the disaggregation? Rupture distance? Epicentral distance? Joyner-Boore distance? Given the depth of the deep sources, the difference between the distance types might be important.

5. Table 2: The authors provide a list of the selected scenarios. A map showing these events might be useful for visualizing the epicenters with respect to the municipalities.

6. Table 3 and its description: Although the logic tree was proposed by Arcila et al. (2020), I suggest the authors provide a justification for the different weights to the Cauzzi et al. (2014) and Abrahamson et al. (2014) ground-motion models.

7. ***Important comment*** In Line 105, the authors state that "The majority of the building stock of the region is comprised of one- and two-story houses." However, as shown in Table 4, the considered building typologies include buildings with either 1 or 4 stories. The question is then, how are two-story houses classified into this system? This question is especially important because it has been previously demonstrated that one- and two-story houses present a significantly different seismic behavior and therefore levels of damage and losses (see, for instance, Heresi and Miranda 2022). In particular, classifying two-story houses as one-story structures may result in a significant underestimation of the seismic risk of these two-story structures.

Heresi, P., & Miranda, E. (2022). Evaluation of relative seismic performance between one- and two-story houses. *Journal of Earthquake Engineering*, *26*(2), 857-886.

8. Table 5 presents the main parameters of the considered fragility curves. As stated by the authors, these fragility curves were selected from different studies after a thorough literature review. Although this is perfectly fine, it has an important drawback that should be commented on: the final set of fragility curves comprise curves developed with very different methods (e.g., analytical vs empirical) which have very different reliabilities (e.g., generally speaking, empirical fragility curves developed after earthquakes have higher uncertainties both in the probability of damage and in the ground-shaking intensity). The authors are encouraged to discuss about the limitations and reliability of the considered fragility curves, taking into account the methods, the data, and the assumptions used to develop them. They address some of these issues in the Caveats and Limitations section, specifically the issue of fragility curves not being developed directly for Colombian structures and not having a uniform description of the damage states, but there are other issues that are missing in this section, as those previously stated in my comment.

9. ***Important comment*** Results show that a Mw5.95 event at Chía is expected to cause the collapse of more than 17% of the buildings in the region, and some level of damage in about half of the building portfolio. In particular, 6722 out of 14959 (about 45%) of houses made out of non-ductile unreinforced masonry with adobe block walls (1-story) are expected to collapse, according to the authors. Moreover, in Chía, more than 44% of the buildings are expected to collapse due to this Mw5.95 scenario. These numbers seem incredibly high for a Mw5.95 event at a first glance (even more when the authors state, in Line 441, that these estimates should be considered as a lower bound). Note that these are mean (i.e., expected) values, not low-probability values that might represent a somewhat "worst-case scenario" (or, in other words, somehow answer the question "how big may be the consequence if this earthquake occurs tomorrow?"). To put these numbers in perspective, we can compare them with the damage produced by the 2010 Haiti earthquake, Mw7.0:

- According to DesRoches et al. (2011), the 2010 Haiti earthquake damaged nearly half of the structures in the epicentral region.
- Eberhard et al. (2013) performed two field surveys of: (1) 107 structures in Port-au-Prince, where 30 (28%) of them collapsed and other 35 (33%) had enough damage to require repairs; and (2) 52 structures in Léogâne (closest population center to the epicenter), where 32 (62%) of them collapsed and other 16 (31%) had enough damage to require repairs.
- Rathje et al. (2011) performed a field survey of over 400 structures in Port-au-Prince. Of the 414 surveyed structures, 157 (38%) had significant damage (i.e., collapse or very heavy damage, EMS Grade 4).

Considering that the Haiti earthquake was not only 32 times larger in terms of magnitude, but also affected a more socially vulnerable country, it is expected that a Mw5.95 event in the region of interest would result in considerably less damage and losses, especially if we talk about mean values.

In terms of losses, in Figure 12 we can observe that some of the earthquake scenarios have a 20% probability of producing more than 50% of the total replacement cost as economic losses (about 40% of the GDP of the region!). Considering that these curves were computed neglecting the spatial correlation of ground motion intensities (comment about this below), this probability for such a high loss is extremely large. For perspective, the 2010 Chile earthquake, Mw8.8, produced an economic loss of about 14% of the GDP of the country at the moment of the event.

The previous remarks highlight the importance of comparing risk results from scenario events with previous events to put the numbers in perspective. I suggest the authors include comparisons like the ones proposed above, but also include other events, such as, for example, the 2020 Puerto Rico earthquake, Mw6.4. Moreover, in the Introduction, the authors mention two historical earthquakes that affected the region of interest, which may also be used to evaluate the reliability of the resulting damage produced by the considered scenario earthquakes. These comparisons would further support the risk results of the article.

DesRoches, R., Comerio, M., Eberhard, M., Mooney, W., & Rix, G. J. (2011). Overview of the 2010 Haiti earthquake. *Earthquake Spectra*, *27*(S1), S1-S21.

Eberhard, M. O., Baldridge, S., Marshall, J., Mooney, W., & Rix, G. J. (2010). The Mw 7.0 Haiti earthquake of January 12, 2010: USGS/EERI advance reconnaissance team report. *US Geological Survey Open-File Report*, *1048*(2013), 64.

Rathje, E. M., Bachhuber, J., Dulberg, R., Cox, B. R., Kottke, A., Wood, C., ... & Rix, G. (2011). Damage patterns in Port-au-Prince during the 2010 Haiti earthquake. *Earthquake Spectra*, *27*(S1), S117-S136.

10. Table 10 presents the resulting SVI for the 11 municipalities of the region. Although the authors previously explain the variables involved in this index (Table 6), I have two comments about this:

- I suggest the authors provide more detailed information about how the index of each category is obtained. This explanation would improve the reproducibility of the reported results.
- There are many variables used for the SVI that are strongly correlated. For example, in the "Population" category, there are 7 variables, where, for instance, "Female population" and "Total population" are expected to be strongly correlated, unless the percentage of women varies significantly from one municipality to another for some reason. As the authors did not provide too much detail on how the index is computed, I'm not sure if they tested for collinearity between these variables, for example. We can even expect some correlation between different categories. For instance, municipalities with a high index in Economy will probably have also a high index in Infrastructure. These correlations might result in biased SVI's when all the variables are considered.

11. ***Important comment*** As one of the limitations, the authors state that they did not consider the spatial cross-correlation when modelling the ground motion fields. However, they do not justify this arbitrary exclusion. For example, the OQ-Engine has models of spatial correlation already implemented, and therefore I do not see a good reason for neglecting it. As the authors correctly state, the inclusion of a spatial correlation model would increase the dispersion of the curves presented in Figure 12, making them more "realistic". Thus, I suggest either including a spatial correlation model, or giving a strong justification for its arbitrary exclusion.

Technical corrections

- Line 43: Change "7248 injured" for "7248 injured people" or "7248 injuries".
- There is an inconsistency in the use of thousand separators. For example, in Line 45 the authors state "… and 35000 buildings that collapsed…", but then in Line 86, they write "resulted in 200,000 deaths". In Table 1, the authors use thousand separators again.
- Line 118: Review the word "gro".
- Line 158: The authors use the Quetame earthquake for defining the rupture geometry of the scenario events. I suggest adding an annotation in Figure 3, showing which one is the Quetame earthquake, for those of us who are not familiar with the historic seismicity of Colombia.
- Line 249: There is an incomplete phrase.